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ISOLDE and Neutron Time-of-Flight Experiments Committee

Report on experiment IS381 and request for additional beam time

Isospin mixing in N ≈ Z nuclei

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Introduction

The goal of experiment IS381 is the study of isospin impurities near the N = Z line by determining the isospin-forbidden Fermi-matrix element in $J^{\pi} \rightarrow J^{\pi}$ β^{+} transitions. This is done by polarizing nuclei with the low temperature nuclear orientation method (NICOLE set-up) and then measuring the beta emission asymmetry. From the measured asymmetry parameter (A_1) one gets the Fermi/Gamow-Teller mixing ratio. Combining this with the ft-value of the transition and with the average ft-value for the superallowed $0^{+} \rightarrow 0^{+}$ transitions then yields the Fermi matrix element. This approach probes the amount of mixing of the isobaric analog state (with isospin T+1) of the daughter state, into the parent state (isospin T).

The aim is twofold. First, information obtained from these experiments contributes to the study of nuclear structure near the N = Z line as isospin mixing is enhanced there due to an increased overlap between the proton and neutron wave functions. Second, the comparison of the measured values for the Fermi matrix elements with theoretical calculations are also of interest for the set of superallowed $0^{+} \rightarrow 0^{+}$ Fermi transitions and the CKM-unitarity problem, since an independent test of the model used to calculate isospin impurities would strengthen the often questioned reliability of the δ_c-values calculated for these transitions.

The methodology for this type of measurements had been optimized in an experiment to determine the isospin impurity in the $6^{+} \rightarrow 6^{+}$ β^{+} decay of ^{52}Mn ($t_{1/2}$ = 5.6 d) in Leuven, which has also settled the long standing controversy with respect to the magnitude of the isospin admixture in this case. This was published in P. Schuurmans et al., Nucl. Phys. A 672 (2000) 89.

Results

In the original proposal three isotopes were proposed: ^{59}Cu, ^{71}As and ^{104m}Ag. Beam time was granted for the first two isotopes, that are produced with the same target for different ion sources.

The isotope ^{71}As ($t_{1/2}$ = 65.3 h) was collected twice and then measured off-line. In the first measurement planar HP Ge detectors (thickness 3mm) were used. The second measurement was carried out with Si p-i-n diodes (thickness 0.5 mm). All detectors were installed inside the 4 K radiation shield of the ^{3}He-^{4}He dilution refrigerator in which the ^{71}As nuclei were cooled to millikelvin temperatures and oriented. In this way the detectors are looking directly at the radioactive source, which eliminates the disturbing effects from scattering in heat shields that would otherwise be present between the source and the detectors. The experimental beta spectrum recorded with a HP Ge detector is shown in Fig. 1. In Fig. 2 the measured beta asymmetry parameter A_1 for the $5/2^{-} \rightarrow 5/2^{-}$ β^{+} transition of ^{71}As is plotted as a function of the positron energy. The fact that only a rather small slope is observed indicates that effects of scattering (mainly backscattering on the detectors) and of the external magnetic field (needed to polarize the ^{71}As nuclei) on the beta particles are rather small. Fitting the data yielded for the beta asymmetry parameter A_1 = -0.296(10), corresponding to an isospin impurity amplitude of $|\alpha|$ = 3.1(3) x 10^{-3} (preliminary values). A publication is being prepared now.

In September 2002 the measurements with ^{59}Cu were carried out. Figure 3 shows the observed anisotropy in the positron distribution as a function of temperature, down to about 6.5 mK. As the nuclear magnetic moment of the ground state of ^{59}Cu was not known it had to be determined as well. NMR-precision (i.e. 10^{-3} precision) was required to avoid that the

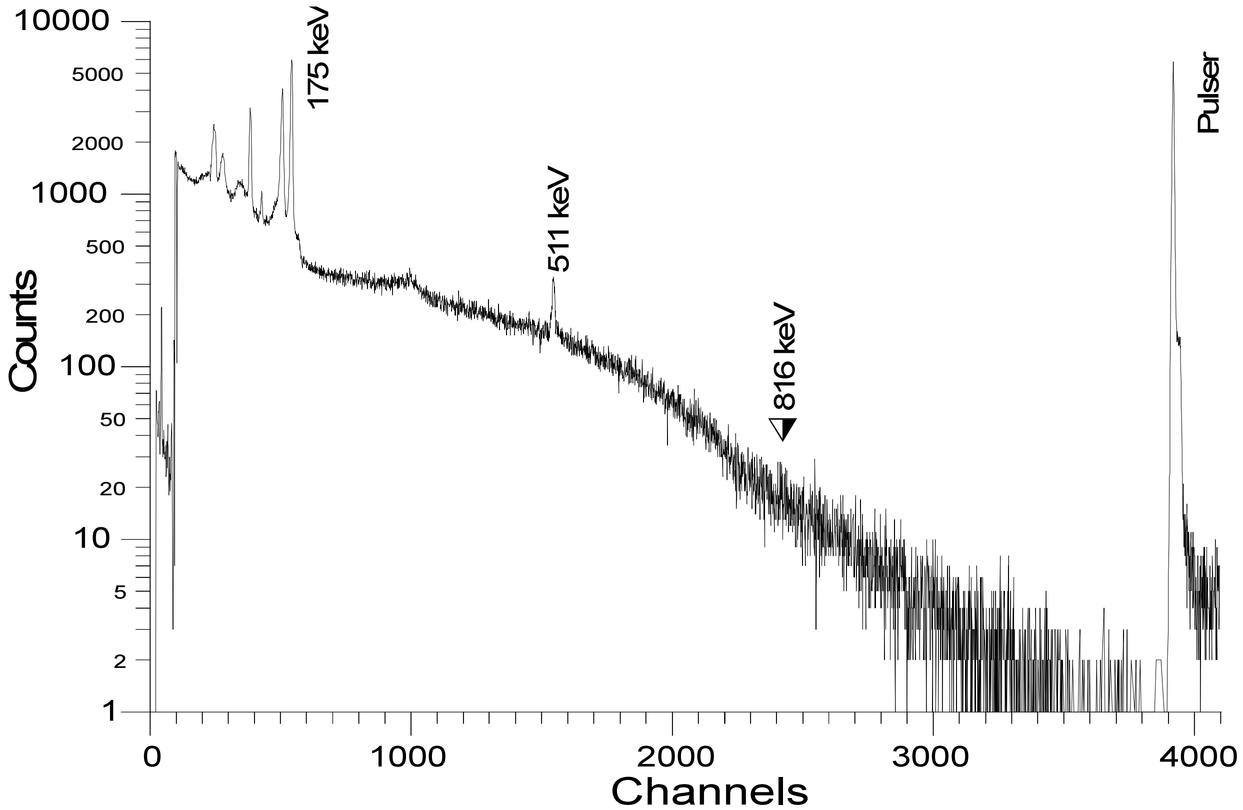

Figure 1. Beta spectrum for ^{71}As taken with a 3 mm thick planar HP Ge detector.

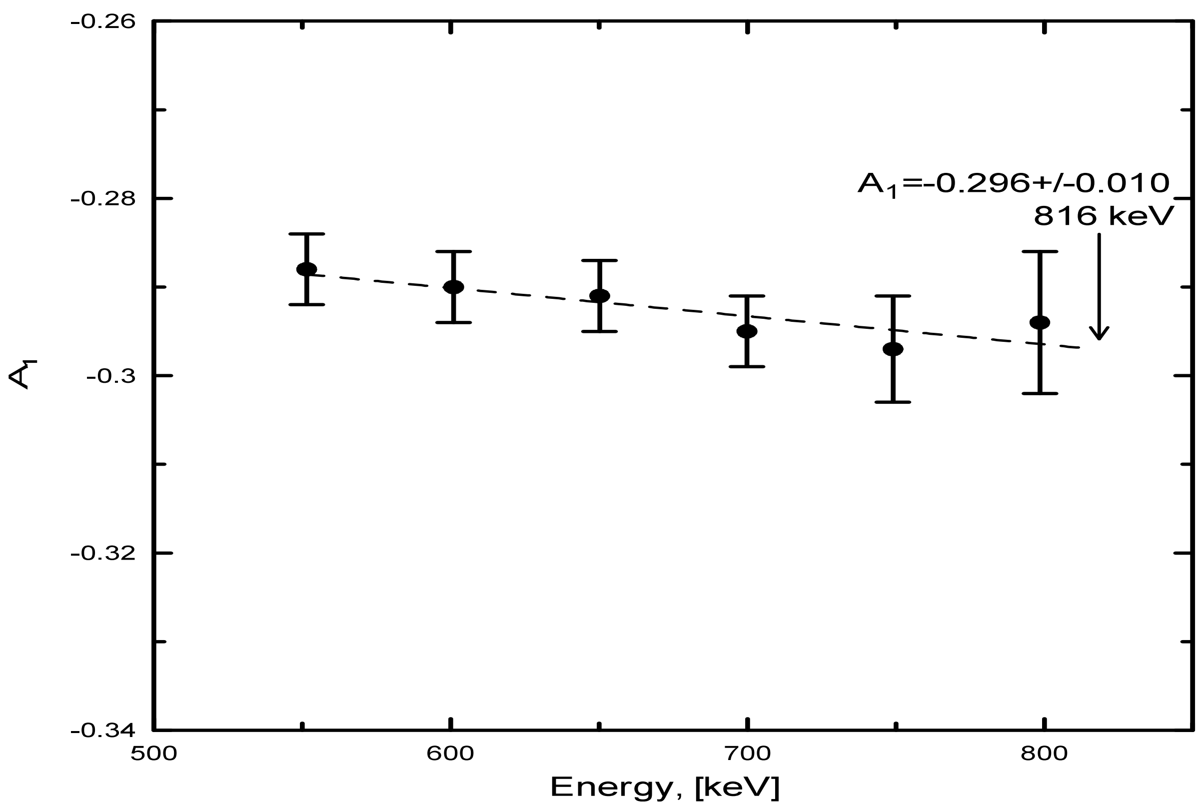

Figure 2. The beta asymmetry parameter A_1 for the $5/2^- \rightarrow 5/2^-$ β^+ transition of ^{71}As as a function of the positron energy (endpoint = 816 keV), together with the fit result.

precision with which the magnetic moment – and hence the degree of nuclear orientation - is known would limit the precision obtained for the beta asymmetry parameter. At the beginning of the run the moment was first determined with 10^{-2} precision by U. Köster, by measuring the hyperfine splitting directly in the laser ion source. This value, the large experimental beta anisotropy (cf. Fig. 3) and the good statistics then allowed us to find the resonance rather fast when applying the NMR method on the oriented ^{59}Cu nuclei in the NICOLE refrigerator. The resonance curve as a function of the rf-frequency that was obtained in this NMR/ON experiment is shown in Fig. 4. It is to be noted that although the measurement of the magnetic moment of ^{59}Cu was needed for anisotropy calibration purposes here, this result also completes the series of moments of odd-Cu isotopes studied by the Oxford nuclear orientation group (experiment IS358). The analysis of the ^{59}Cu dataset is still ongoing.

Request for additional beam time

In order to complete this project we would like to carry out measurements for three more isotopes, i.e. ^{104m}Ag, ^{57}Ni and ^{69}As. An overview of the properties of the already measured isotopes as well as these proposed here is given in Table 1. Calculations of the Fermi matrix elements for these transitions will be performed by B.A. Brown (private communication).

Table 1. Main properties of the isotopes and beta transitions of relevance to this experiment.

Isotope	$T_{1/2}$	J^{π}	E of final state (keV)	Endpoint energy (keV)	T	$\lvert M_F \rvert \times 10^3$	$\lvert\alpha\rvert \times 10^3$
^{52}Mn	5.6 d	6^+	3114	576	1	5.2(12)	2.6(6)
^{71}As	65.3 h	$5/2^-$	175	816	5/2	8.2(4) prelim.	3.1(3) prelim.
^{59}Cu	82 s	$3/2^-$	0	3778	1/2	under analysis	under analysis
^{57}Ni	36 h	$3/2^-$	1378	864	1/2	proposed	proposed
^{69}As	15.4 m	$5/2^-$	0	2988	3/2	proposed	proposed
^{104m}Ag	33 m	2^+	556	2701	5	proposed	proposed

The first isotope proposed here, i.e. ^{104m}Ag, was already part of the original proposal. A measurement on ^{104m}Ag is important as this isotope has T = 5, which is much larger than that of all other isotopes, thus extending the systematics to large isospin values. ^{104m}Ag can be produced indirectly as daughter of ^{104}Cd with a liquid Sn target. Because the ^{104g}Ag and ^{104}Cd isobars have a beta endpoint energy that is smaller than that of ^{104m}Ag, these isotopes will not disturb the measurement. ^{104}Sn and ^{104}In, however, have a larger endpoint energy and these should therefore be avoided. Tin is obviously not released from a liquid tin target, while In can be suppressed by controlling the line temperature.

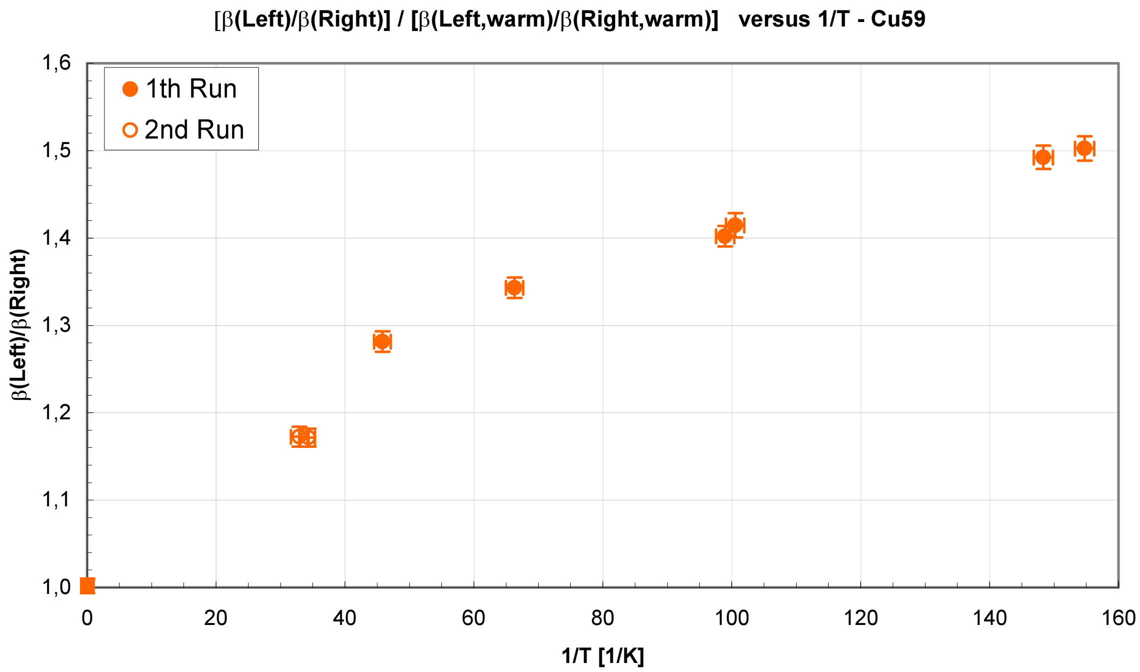

Figure 3. Beta anisotropy as a function of inverse temperature (down to about 6.5 mK) for ^{59}Cu (preliminary / on-line data).

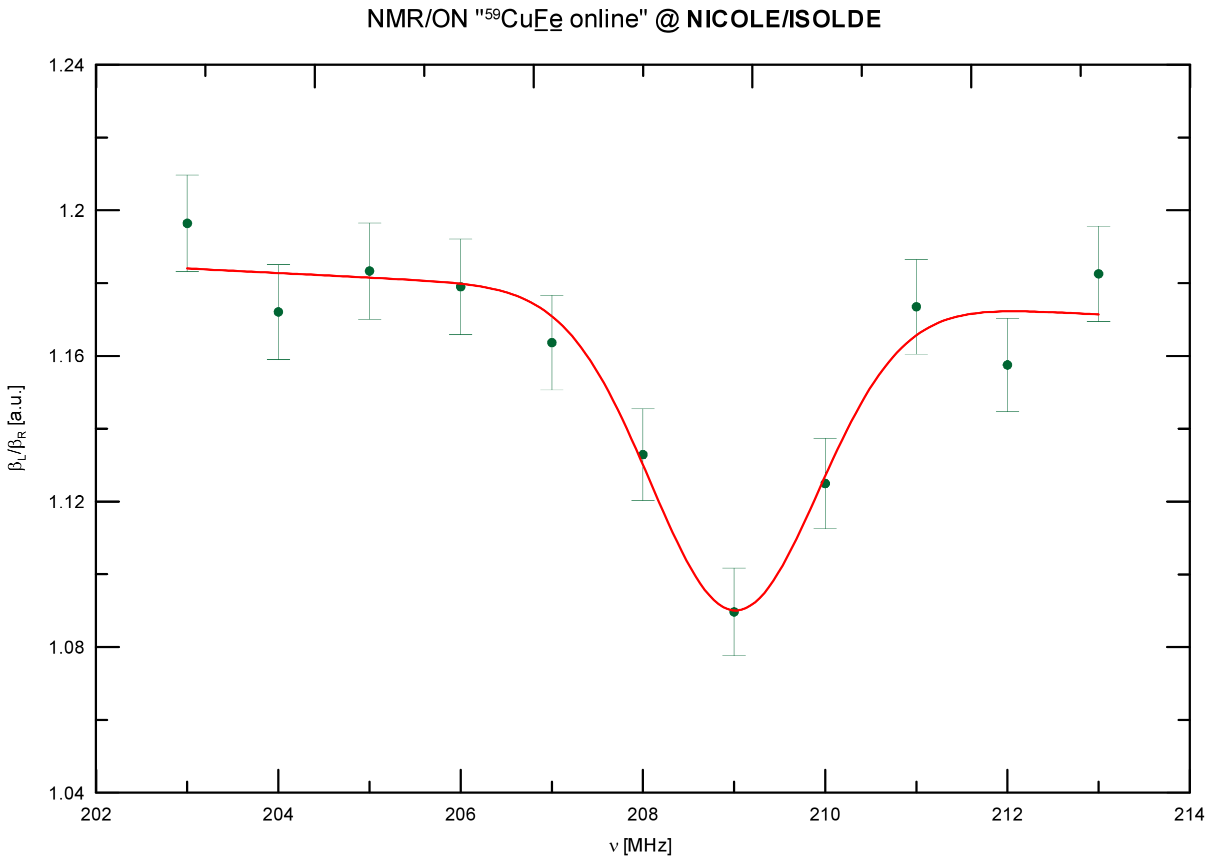

Figure 4. NMR/ON resonance result for ^{59}Cu.

Since the magnetic moment of ^{104m}Ag is not known with sufficient precision yet (values of 3.7(2) μ_N and 4.12(25) μ_N are available in the literature – O. Ames, Phys. Rev. 123 (1961) 1793) we will have to measure this with NMR/ON, as we did for ^{59}Cu.

An experiment with ^{57}Ni is of special interest as a previous measurement of the isospin impurity in the $3/2^- \rightarrow 3/2^-$ beta transition of this isotope – using the $\beta\gamma$ circular-polarization angular correlation technique - (J. Atkinson et al., Nucl. Phys. A 114 (1968) 143) has yielded a surprisingly large isospin impurity amplitude of $|\alpha| = 8.4(17) \times 10^{-3}$. A new experiment with a pure sample, as can be obtained at ISOLDE, would allow to settle this question. For ^{57}Ni a yield of $6 \times 10^4/\mu C$ was measured with a ZrO_2 target with hot plasma source. Since a standard Nb foil target is about 6 to 8 times thicker than the ZrO_2 target a yield of the order of $4 \times 10^5/\mu C$ can be expected. Another one to two orders of magnitude in intensity could probably be gained with the laser ion source due to its higher efficiency for Ni ionization. However, already with a yield of about $5 \times 10^5/\mu C$ a sufficiently strong ^{57}Ni sample can be collected in two shifts and then be measured off-line ($t_{1/2}$ = 36 h).

Finally, we suggest to measure also the isospin impurity in the $3/2^- \rightarrow 3/2^-$ beta transition of the isotope ^{69}As with isospin T = 3/2. This measurement would provide important additional information about the admixture amplitude in case of small isospin values, for which the admixtures are expected to be largest. Since the magnetic moment of ^{69}As is not known with sufficient precision yet we will have to measure this with NMR/ON also in this case. Also, whereas for ^{57}Ni and ^{104m}Ag the implantation quality (i.e. the so-called fraction of nuclei at substitutional lattice sites) can be obtained from the gamma-decay of these isotopes themselves, this is not possible for ^{69}As. This fraction can be determined, however, from a measurement of the gamma-ray anisotropies in the decay of ^{70}As, during the same run and implanted into the same Fe foil in which ^{69}As is implanted. ^{69}As can be produced both from a Nb foil or a ZrO_2 target with a hot plasma ion source. A difficulty here is that all isobars are also in the beam. The isobars ^{69}Ge and ^{69}Zn do not pose any problem as their beta endpoint energy is well below that of ^{69}As. However, ^{69}Se has a larger beta endpoint energy and will thus contaminate the beta spectrum of ^{69}As. Fortunately the yield for ^{69}Se (i.e. $2 \times 10^3/\mu C$, measured with a ZrO_2 target at the SC) is about 4 orders of magnitude smaller than that of ^{69}As ($2 \times 10^7/\mu C$). Even if this ratio would be worse by one order of magnitude at the PSB with 1.4 GeV protons, this will not affect our experiment at the typically 1% precision that is reached for the beta asymmetry parameter with our method.

Data handling requirements

We will provide our own data handling equipment.

Beam time request

- For ^{57}Ni we ask 2 shifts for the collection.
- For ^{69}As 6 shifts are needed to measure the beta asymmetry with good precision, 3 shifts to determine the magnetic moment of this isotope with NMR/ON, and also 3 shifts to measure the gamma-ray anisotropies of ^{70}As, in order to determine the implantation quality for As in the Fe foil used.

- For ^{104m}Ag we ask 1 shift with the laser ion source and a La_xC/graphite or a U Carbide target and 9 shifts with a liquid Sn target and a hot transfer line. The first is to determine the magnetic moment by in-source laser spectroscopy. If the moment is first determined with this method this will significantly reduce the otherwise large search region for this isotope with NMR/ON. Indeed, the frequency region we would have to search with NMR/ON is from about 600 MHz to 750 MHz if only the one standard deviation errors for the above mentioned magnetic moments of 3.7(2) μ_N and 4.12(25) μ_N are considered. This would require about three to five times more beam time, compared to the 1 shift needed for the laser scan. Once the frequency region will be significantly reduced by the result from the laser scan, the moment can be determined with about an order of magnitude better precision with the NMR/ON method. The higher precision is needed to avoid that the accuracy with which the magnetic moment is known would limit the final precision for the beta asymmetry parameter
  The 9 shifts with the liquid tin target will be used for the experiments at NICOLE with ^{104m}Ag, i.e. 3 shifts to determine the magnetic moment with NMR/ON and 6 shifts to measure the beta asymmetry.

Beam	**Min. intensity**	**Target material**	**Ion source**	**Shifts**
^{57}Ni	5 x 10^5	Nb foil	hot plasma source	2
^{69}As	5 x 10^6	Nb foil or Zr Oxide	hot plasma source	9
^{70}As	5 x 10^6	Nb foil or Zr Oxide	hot plasma source	3
^{104m}Ag	5 x 10^6	La_xC/graphite or U Carbide	laser ion source	1
^{104m}Ag	5 x 10^6	liquid tin	hot transfer line	9